In Vivo Microultrasound Visualisation of Nerve Trauma Due to Regional Anaesthesia Needle Insertion and Injection

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In vivo microultrasound visualisation of nerve trauma due to regional anaesthesia needle insertion and injection

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Abstract*— Regional anesthesia is indicated and commonly used for many surgical procedures. However, intraneural needle insertion and injection is frequent, though unintended, resulting in 10% of patients having post-operative peripheral nerve pain, affecting recovery. The incidence of neuropathy has not decreased over the last decade despite the adoption of ultrasound guided regional anesthesia because of the difficulty interpreting the needle tip position relative to nerves with standard clinical ultrasound imaging systems. This study uses microultrasound for visualising the anatomy of the nerve in the pig model and for confirming the placement of the anesthetic needle while delivering injectate near or in a nerve. The in-line fluid pressure is measured during the injection for different clinical flow rates used during the regional anesthesia procedure. The change in shape and the displacement of the nerve due to the injection is evaluated, and fluid pressure associated with intraneural and extraneural injection. The analysis of the different factors contributing to the nerve trauma showed that there was significant change in pressure measurement with different pigs, flow rate and tissue layers where the needle tip was placed.

Keywords*— Microultrasound, regional anesthesia, peripheral anaesthesia, anaesthetic fluid pressure, nerve injury, peripheral nerves,

I. Introduction

Regional Anesthesia, which involves injecting anesthetic around peripheral nerves, is used for many surgical procedures to numb peripheral nerves. A needle is positioned beside the nerve, often under ultrasound guidance, and used to deliver anesthetic fluid around a nerve. Intraneural injection is unintended but frequent and 10% of patients have acute or chronic peripheral nerve pain post-surgery. Two clinical studies showed that forceful needle nerve contact was associated with peak needle tip pressure ≥ 15psi in between 90% [1] and 97% of patients [2]. In a dog study, peak intraneural needle tip pressure was > 25 psi and associated with inflammation and cell death in 4 out of 7 dogs [3]. However, the remaining three intraneural injections resulted in peak needle tip pressure <11psi. Ex-vivo and peak injection pressure differs according to the rate of injection, volume of injectate, needle gauge, length of needle, nerve composition (ratio of connective tissue to nerve fascicles), and syringe diameter [4]. Factors that can contribute to nerve damage include mechanical trauma, high injectate pressure (recommended maximum: 15 psi) and high flow rate, but the mechanisms are poorly understood and disputed. The relationship between local anesthetic flow rate, injectate pressure with epineural or intraneural needle tip placement, and nerve damage remains unresolved for regional nerve blocks. There is therefore a need to investigate the relationship between local anesthetic flow rate, fluid pressure and nerve damage. There is also a need to observe, in real-time, the effect of intraneural injection on the structure of the nerve.

This study uses microultrasound imaging in an anaesthetised pig model to visualise the changes in nerve geometry, the fascicles (bundles of neurons) and epineurium (protective connective tissue surrounding the nerve) concurrently with measurement of injectate pressure during replicated RA nerve blocks in order to better understand physical mechanisms of nerve damage.

II. Experimental Methods

The in vivo animal study was performed with the approval of the local animal committee (Sunnybrook Research Institute Animal Care Committee). Exemption of controlled medical substance were obtained according to the Controlled Drugs and Substances Act (CDSA) and Narcotic Controlled regulations, Health Canada.

A. Measurement and experimental setup

The experimental set up is shown in Fig 1. Both microultrasound videos and inline pressure measurements were recorded of anaesthetic needle insertion through the muscle, fascia, and into the nerve. Microultrasound (40 MHz array: VS550 & VEVO 2100, VisualSonics Inc.) videos were acquired to have sufficient resolution of the internal structure of the nerve, in particular the fascicles. When the microultrasound probe is placed within about 10 mm of the nerves, the epineurium, fascicles and interfasicular tissue can be clearly visualised.

The pressure of the injectate fluid was measured at 2 s increments using a digital biological manometer. Pressure was recorded for the duration of the RA procedures on each

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pig. An in-line pressure sensor (PressureMAT, PendoTech, New Jersey) was attached between the luer lock 21G regional block needle and a mechanical syringe pump.

The 21G needle was inserted through muscle and/or fascia and into nerves. This was followed by 0.5 mL saline injection at 6 or 12 mL/min controlled using a programmable syringe pump. The bolus replicates a test dose of anaesthetic fluid used by the anaesthetist to confirm needle tip location and fluid distribution. For select test procedures, a 1 mL/min flow rate over 2 minutes was used to evaluate continuous fluid distribution during the RA procedure and to obtain pressure measurement with continuous fluid flow without delivering too much saline into the tissue. The flow rates were chosen as subclinical and clinical flow rates. The 1 mL/min rate is much slower than the typical injection rate achieved in standard clinical settings, whereas 6 mL/min and 12 mL/min are clinical flow rates and typical fluid flow rates with manual depression of an anaesthetic syringe. The time taken for the delivering the fluid into the nerve at the flow rates 6 mL /min and 12 mL /min are 5 sec and 2.5 sec respectively.

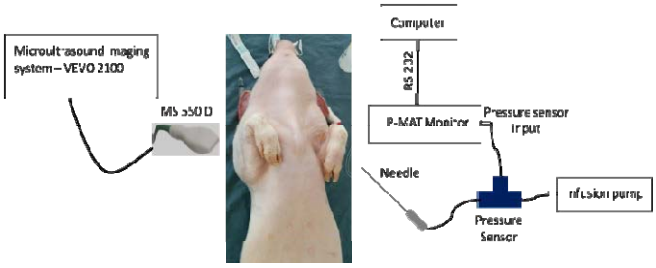

Fig 1: Experimental set up for imaging the nerve trauma using Microultrasound and measurement of pressure during needle insertion and fluid injection into the nerve

The 0.5 mL saline injection was performed at three sites on each nerve, approximately 5 cm apart. Measurements were acquired for both left and right axilla, for 18 test sites per pig. The study was randomised to two operators performing the regional anesthesia procedure (expert and novice), in-plane and out-of-plane needle trajectories and flow rates of 1 mL/min, 6 mL/min and 12 mL/min. These are the different parameters that were considered in evaluating the contribution to nerve trauma during regional anesthesia. The summary of the parameters is given in Table 1.

B. Replicated regional anaesthesia procedure

Pigs were anaesthetized using ketamine 15 mg/kg^{-1}. Vital signs were monitored continuously. Temperature was maintained using a heating blanket and fluids administered intravenously. The pig was positioned in dorsal position for imaging the anatomy of the nerves and nerve trauma caused by the anesthetic needles. The brachial plexus of anesthetized pigs was surgically exposed to access the median, ulnar, and radial axillary nerves easily with the anaesthetic needle and the microultrasound probe. The nerves were identified from the brachial plexus branching and the tissue was dissected to a few millimeters above the nerve in order to acquire high resolution images of the nerve anatomy and nerve trauma using microultrasound. Set agar (2-3%) slabs were used as a stand-off to optimise the microultrasound images. Standard 21 G anesthetic needle was inserted into the nerve and a test dose of 0.5 mL saline solution was injected around and inside the nerve during replicated regional anesthesia nerve blocks. Multiple needle insertions and fluid injections into the tissue were carried out along the length of each peripheral nerve, with needle tip position as extraneural, forceful needle nerve contact, interfascicular (inside the nerve, but outside the fascicles), Intrafascicular (inside the nerve, within fascicles).

The sequence of events and the acquisition time of the microultrasound images and the corresponding pressure measurement were recorded. Observations of potential mechanisms of nerve damage observed with the microultrasound imaging were also noted during the procedures.

TABLE I. FACTORS CONSIDERED TO CONTRIBUTE TO NERVE TRAUMA

Parameters	Parameter Variables
Test Specimens	Four pigs
Experimental Side	Left and Right
Nerves	Median, Radial and Ulnar
Needle insertion site	Upper (at branching), Mid and Lower (separated by approx. 5 cm)
Plane of trajectory	In-plane and Out-of-plane (relative to ultrasound image)
Operators	Expert; Novice
Flow rates	1 mL/min, 6 mL/min, 12 mL/min

Needle tip position, nerve structure changes and fluid distribution were recorded for 235 individual injections across 56 block procedures on 4 pigs. Injection with the needle tip extraneural, in forceful contact with nerve epineurium, and intraneural were attempted to replicate clinical practices that may lead to nerve damage

III. RESULTS

Microultrasound enabled in vivo, real-time visualisation of the fascicle structure in all of the attempted blocks. Fascicles as small as 0.4 mm can be resolved with microultrasound, making it suitable for real-time monitoring of nerve motion. The effects of needle position and injectate distribution on fascicles and epineurium were correlated with injectate pressure (Fig 2).

Intraneural injection was characterised by swelling of the whole nerve, swelling immediately around the nerve, rupture of the epineurium, and/or failure to return to pre-injection morphology on needle withdrawal. The intraneural injections observed in the microultrasound videos could be categorised into four types: intraneural expansion of the nerve, peripheral expansion of tissue surrounding the nerve, combination of intraneural expansion of the nerve and peripheral expansion of the tissue and intraneural expansion of the nerve with causing damage to the nerve. In the later scenario the nerve fails to return to its original shape and size.

Fig 2 shows microultrasound image frames showing radial nerve, ulnar nerve, medial nerve and fascicles. Fig 2(i) shows the radial nerve before needle insertion and fluid injection. The second microultrasound image shows the needle being inserted into the nerve in an attempt to perform intraneural

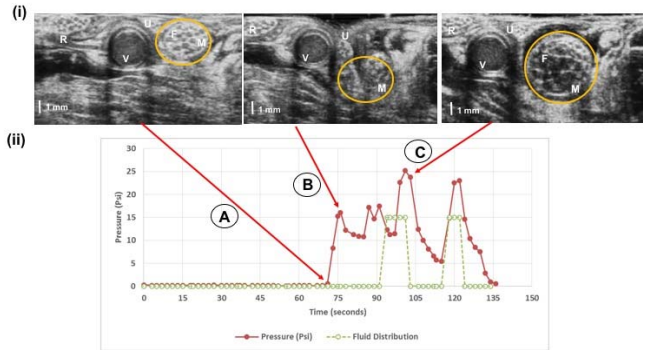

Fig 2:(i) Micro US image frames showing R- radial nerve, U- Ulnar nerve, M- Median nerve, F- fascicles and V- Vessel (ii) pressure measurement (red dots) during needle insertion into median nerve (marked in yellow circle) and 0.5 mL bolus injection (at 6 mL/min). Needle tip position / fluid distribution during injection (green dots): A – before needle injection/no fluid delivery; B – Tenting of the nerve, as the needle tip tried to penetrate the epineurium/Fluid injection starts when the needle is on the epineurium with fluid distribution outside of nerve, continuing to intraneural injection; C – First Intraneural injection showing expansion of the nerve and distribution of fluid around the nerve /end of fluid injection.

injection. The dent of the needle can be seen, and is an example of forceful needle-nerve contact. Multiple attempts have been made to insert the needle within the nerve in order to perform intraneural injection. The third microultrasound image in that series shows the nerve while fluid is being injected into the nerve. The images show the intraneural expansion of the nerve, where the fluid tends to spread out equally inside the nerve, causing the nerve to expand. The nerve tends to return back to its original size and shape in this case. Fig 2(ii) shows the pressure measured (red dots) during the needle insertion and fluid injection procedure and the corresponding fluid delivery is marked (green circles). Throughout the procedure, injectate pressure measured when the needle is against the muscle was noted to be low, when compared to fascia, epineurium and intraneural injections. Fascia and epineurium are tough connective tissue and it is difficult to penetrate these tissues with ease. The peak pressure in the graph is caused by needle tip against fascia, epineurium and intraneural in this case (Fig 2).

The relationship between different experimental parameters and contribution to increased pressure or nerve trauma were analysed. An example graph for pig 4 is given in Fig 3. The scatter plot shows the relationship between the measured inline pressure and the tissue in which needle tip was located during injection (Muscle, fascia, epineurium and intraneural), for the two different clinical flow rates, 6 mL/min and 12 mL/min. A trend in increased pressure is observed when the needle tip is placed intraneurally.

Nevertheless, if the opening of the needle tip is away from the nerve tissue then for the same scenario the pressure measured can be low. The highest pressure recorded for 6 mL/min and 12 mL/min for pig 4 was 13.28 psi and 60.02 psi respectively. Injectate pressure was measured to be <15 psi in 47% of intraneural injection and needle-epineurium contact, indicating the limit should be reduced. The onset of nerve structure changes could be easily observed at 1 mL/min flow rate, with time to stop or reposition the needle and therefore change the distribution of the injection. Due to the multiple factors contributing to the nerve trauma, it is very difficult to find significant relationship between these factors using simple statistical tools. A multivariate analysis is required to understand the effect on injectate pressure of the experimental parameters listed in Table 1, and will be presented in future reports.

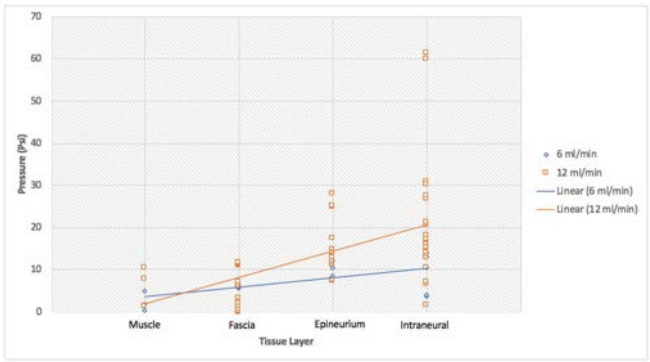

Fig 3: Relationship between tissue layer and pressure at different flow rates

IV. CONCLUSION

In conclusion microultrasound gave a better insight of the consequences of inserting a needle into the nerve and the extent of mechanical trauma caused by injection of fluid into the nerve. Several factors contributing to the nerve trauma were studied and analysed. Intraneural injections corresponded with higher injectate pressure than extraneural injections, but with large variability. A continuous flow at low flow rate (e.g 1 mL/min) may be suitable for avoiding intraneural injection.

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